

BRUSHLESS MOTOR HAVING DOUBLE INSULATION

FIELD OF INVENTION

[0001] The invention relates generally to electronically commutated brushless motors, such as switched reluctance motors, high frequency induction motors, brushless AC motors, and brushless DC motors. More particularly, the invention relates to an electronically commutated brushless motor design and assembly process that provides a robust brushless motor capable of meeting the unique functional requirements in various applications, such as portable table saws, miter saws, site saws, and TGS-type combination saws.

BACKGROUND OF THE INVENTION

[0002] Prior art electronically commutated brushless motors suffer from various limitations. One limitation is a restriction of airflow through the motor. In a typical universal motor housing, air is drawn in through vents in an end cap, passes over a brush gear assembly and windings, through a fan and exhausts out the other end of the motor.

[0003] In an electronically commutated brushless motor, air is also drawn in through an end cap but first must pass around the periphery of an electronics control module, installed at one axial end of the housing, before the air can pass through the rest of the motor. Thus, the electronics control module,

which includes a potting boat holding an encapsulated printed circuit board (PCB), impedes the airflow by causing the air to first pass around the electronics control module. After passing around the electronics control module the air passes down through channels created by extruded fins of aluminum heat sinks, thereby cooling electronic components attached to the heat sinks. The air then continues over stator windings, passes through and around the stator, through a fan and exhausts out through the end of the motor. Thus, in electronically commutated brushless motors the electronics control module restricts the airflow through the motor.

[0004] The obstruction to airflow in electronically commutated brushless motors is further compounded by the housing molding process. To effectively mold and produce the housing, it must have draft added on both its internal (core) and external (cavity) sides. Since the geometry at the mouth of the housing is fixed by mounting interface requirements with existing products, the draft closes (i.e., narrows) the housing down about the electronics control module, thereby further restricting the airflow around the electronics control module and through the motor.

[0005] A second limitation of known electronically commutated brushless motors is that the motor is typically longer than a typical universal motor. Due to the longer motor, electronically commutated brushless motors are difficult to utilize in many power tools where it is desirable to keep the overall axial length of the motor, or housing, as short as possible. This is especially true

10014711-12101

with saws, such as miter saws and other saws, because when the saw (and the motor coupled to the saw) is tilted at an angle, an extra long motor housing can cause interference with a fence or the table of the saw. For example, in a TGS-type combination saw, the axial length of the motor housing must be short enough so that it does not protrude beyond the frame of the saw. If it does it will prevent the table from being flipped over. As another example, the axial length of the motor in a small portable table saw should be such that when attached to the saw gear case, the motor housing should fit inside the skirt that forms the base of the table. As yet another example, in a miter saw, where the bevel and miter functions will tip the end of the motor towards the table, the axial length of the motor should be such that the motor does not contact the table fence.

[0006] A third limitation of known electronically commutated brushless motors is the inability to insure proper alignment of the registering means on the rotor shaft with the rotor pole, and the position sensor with the stator during the assembly process. The registering means could be any suitable registering means such as an interrupter or a magnet, and the position sensor could any suitable sensor such as an optical sensor or a Hall Effect sensor. In typical electronically commutated brushless motors, the position of the registering means, relative to the position sensor, determines the position of the rotor, relative to the stator. In electronically commutated brushless motors it is critically important to know the exact position of the rotor when the electronic switching signals, which switch the direction of the flux in the motor winding(s),

are provided by an electronic controller. If the alignment of the registering means with the rotor pole is off, or the alignment of the position sensor with the stator is not precisely set, then the position of the registering means, as detected by the position sensor, will provide an inaccurate indication of the position of the rotor, relative to the stator. If the position of the rotor is not accurately determined, the electronic switching motor will very quickly lose power and torque.

[0007] A fourth limitation of known electronically commutated brushless motors is meeting the requirements for double insulated construction as described by Underwriters Laboratories (UL) and other compliance agencies. Double insulated motor designs, which eliminate the need for a ground wire in the power cord, have been implemented on universal motors. This is a preferred construction for hand held and table mounted power tools since the alternative, grounded tools, rely on there being a solid ground connection available on a job site, which often is not the case. The basic requirement is that the design must provide at least two levels of insulation between live components, such as the windings, and any metallic components, such as the shaft or screws, that are accessible to the user. Known electronically commutated brushless motors do not implement a double insulated construction design.

[0008] Therefore, it would be desirable to provide an electronically commutated brushless motor design that provides increased airflow through the motor. It would further be desirable provide an electronically commutated

brushless motor having an overall axial length suitable for applications requiring a shorter motor. Even further, it would be desirable to provide an electronically commutated brushless motor design that insures accurate alignment of the optical encoder with the rotor poles, and accurate alignment of the optical sensor with the stator during assembly of the motor. Further yet, it would be desirable to provide an electronically commutated brushless motor that implements a double insulated design without significantly increasing the cost or complicating the manufacturability and/or assembly of the overall motor.

BRIEF SUMMARY OF THE INVENTION

[0009] The present invention relates to an electronically commutated brushless motor design, which overcomes the various drawbacks described above. In a preferred form, the invention relates to brushless AC motor, although it will be appreciated that the invention is also applicable to brushless DC motors.

[0010] In one aspect of the present invention a housing of the motor is provided with a draft angle that increases the airflow through the housing to allow more efficiently cooling of the motor.

[0011] In a second aspect of the present invention the electronically commutated brushless motor design provides a capacitor mounting arrangement that allows the overall axial length of the motor to be made shorter. The capacitors are mounted on a circuit board, which is adapted to slide into a

housing protrusion, or bulge, formed on the sidewall of the housing rather than at one axial end of the housing. Thus, the overall axial length of the housing is made shorter, thereby allowing a wider range of applications for the motor in which the motor must be situated into different positions without interfering with other components of its associated tool.

[0012] In a third aspect of the present invention the electronically commutated brushless motor provides a housing that allows accurate alignment of a stator and a position sensor, such as an optical sensor, relative to each other. This is accomplished by using a housing molding core that produces a housing that includes both a bridge on which the position sensor is mounted, and stator locating ribs. Typically, the molding core for the housing forms locating ribs on an interior surface of the housing, which are used to precisely align the stator when it is inserted into the housing, but does not include a mounting bridge for the position sensor. By molding the housing to include both a position sensor mounting bridge and the stator locating ribs, variances in the positioning of the position sensor, relative to the stator, are avoided. Therefore, the position sensor and the stator will be accurately aligned when installed, without the need for time consuming alignment procedures, or tests, during the assembly of the motor.

[0013] In a fourth aspect of the present invention the electronically commutated brushless motor incorporates a double insulation (DI) feature, thereby eliminating the need for a direct ground cable in the power cord. The DI

design includes insulating strips between the stator and stator windings, and an insulating sleeve disposed between the rotor shaft and the rotor laminations. Therefore, there are two layers of insulation between metal parts accessible to a user and parts of the motor in which electrical current flows. Alternatively, the motor housing, which supports the stator, is also constructed of a non-conductive material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The present invention will become more fully understood from the detailed description and accompanying drawings, wherein;

[0015] Figure 1 is a perspective view of a electronically commutated brushless motor in accordance with a preferred embodiment of the present invention;

[0016] Figure 2 is an exploded view of the motor shown in Figure 1, showing how the components of the motor are assembled;

[0017] Figure 3 is an exploded view of the interior of the distal end of the motor housing shown in Figure 2;

[0018] Figure 4 is an exploded view of the distal end of the motor shown in Figure 2, showing how the components at the distal end of the motor are assembled;

[0019] Figure 5 is an exploded view of the housing shown in Figure 4, showing how film capacitors are slideably inserted into a motor housing bulge;

[0020] Figure 6 is an exploded view of a stator stack shown in Figure 2;

[0021] Figure 7 is an exploded view of the stator and rotor assembly shown in Figure 2;

[0022] Figure 8 is cross-sectional view of the motor shown in Figure 1; and

[0023] Figure 9 is a schematic of the housing of the motor shown in Figure, showing the location of the parting line of the core and cavity used to mold the housing.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Figure 1 is a perspective view of an electronically commutated brushless motor 10 in accordance with a preferred embodiment of the present invention. Motor 10 is a self-contained motor, which can be bolted directly onto a gearbox or other support means of a product, such as a power tool. Motor 10 includes a plastic motor housing 14 having an integrally formed bulge 18 protruding from an outer surface of a sidewall of the motor housing, wherein a plurality of capacitors (not shown) are inserted. Housing 14 is closed

at a distal end by a vented end cap 22, and closed at the opposing proximal end by a bearing end cap 26.

[0025] Figure 2 is an exploded view of motor 10 (shown in Figure 1) showing how the components of motor 10 are assembled. A stator stack 30, a rotor 34 and a baffle 38 are fitted annularly inside housing 14. Stator stack 30 is a stack of steel laminations fitted with stator windings (described in reference to Figure 6 below). The stator windings are sequentially energized with electrical current, thereby generating a revolving magnetic field. Stator stack 30 is precisely positioned within housing 14 using a plurality of locating ribs 40 formed on an inside surface 14a of a sidewall of housing 14. The locating ribs 40 fit into stator channels 42 integrally formed in stator stack 30. Stator stack 30 is then pressed into housing 14, having an interference fit, and secured in place with two screws (not shown).

[0026] Rotor 34 has no windings and is supported between a first bearing 44, supported by bearing end cap 26, and a second bearing 46, supported by an integral bearing support (not shown), incorporated into motor housing 14. Rotor 34 includes a shaft 50, an insulating tube, or sleeve, 54, a stack of steel laminations 58, and a cooling fan 62 that helps to direct air through the motor 10. Stack 58 is assembled by interlocking, welding, cleating, or bonding the steel laminations together. Insulating tube 54 is pressed onto shaft 50 and rotor stack 58 is pressed onto insulating tube 54. Shaft 50 connects to a product gearbox (not shown), which in turn is coupled to a tool element such as

a saw blade. The revolving magnetic field created by the stator windings imparts a force on rotor stack 58 causing rotor stack 58 to revolve about an axis of shaft 50, thereby transferring torque to shaft 50, which in turn delivers torque to gears in the product gearbox. Rotor stack 58 includes a plurality of four rotor poles 68, although it will be appreciated that a greater or lesser plurality of rotor poles 68 could be incorporated.

[0027] Rotor 34 further includes a registering means 66, such as an interrupter. As used herein registering means 66 is referred to as interrupter 66, but it will be appreciated that registering means 66 could be any other suitable registering means, such as a magnet. Interrupter 66 has a plurality of four vanes 66a, only three of which are visible in Figure 2. Interrupter 66 is a plastic part that fits on the distal, or rear, end of shaft 50 and interfaces with a position sensor (described below in reference to Figure 3) to provide data relating to a rotor position and a rotor speed to the electronic controller. Slipping or spinning of the outer diameter (OD) of second bearing 46 is prevented by a compliant material (not shown) that fits between the OD of bearing 46 and the wall of the bearing support, for example a rubber plug or rubber boot. After stator 30, baffle 38 and rotor 34 are annularly fitted into housing 14, bearing end plate 26 is fitted over first bearing 44 and onto locating points at the mouth of housing 14, then secured to plastic housing 14 with four screws (not shown).

[0028] Figure 3 is an exploded view of the interior of the distal end of motor housing 14 (shown in Figure 2). Behind the integral bearing support

//

10014711121101

100471 "12101

(not shown) of housing 14 is a bridge 70, which supports a position sensor 74. In the preferred embodiment, position sensor 74 is an optical sensor, and is herein referred to optical sensor 74. However, it will be appreciated that position sensor 74 could be any other suitable position sensor, for example, a Hall Effect sensor. Bridge 70 is integrally formed with, and protrudes from, and an end wall 72 of housing 14. Optical sensor 74 is inserted under an upper portion 70a of the bridge 70 such that it fits substantially within a hollow area 71 inside the bridge. Optical sensor 74 includes tabs 74a and 74b, with tab 74a including an aperture 75 and tab 74b including an aperture 77. Optical sensor 74 is attached at tab 74b to the bridge 70 by a fastener (not shown), which extends through an aperture 80 formed in upper portion 70a of bridge 70 and through aperture 77. End wall 72 includes a pair of mounting bosses 72a and 72b projecting outwardly therefrom, with each mounting boss having a blind hole 72c and a through hole 72d, respectively. Tab 74a of optical sensor 74 is laid over mounting boss 72b such that aperture 75 and through hole 72d are aligned.

[0029] Once fitted into bridge 70, as described above, optical sensor 74 is covered with a hollow plastic sensor cap 78. Optical sensor 74 is bounded above by cap 78 and below by second bearing 46, which form a sealed chamber for housing optical sensor 74. The sealed chamber protects optical sensor 74 from contamination by dirt, dust, oil and moisture, and accidental triggering by external light sources. Additionally, the distal end of motor housing

14 includes a boss 81 used in attaching vented end cap 22 (shown in Figure 1) to the distal end of motor housing 14.

[0030] Optical sensor 74 interfaces with interrupter 66 (shown in Figure 2) to provide data relating to rotor 34 position and speed. As shaft 50 and interrupter 66 rotate, the passing of vanes 66a of interrupter 66 is detected by optical sensor 74, which provides data to a main control PCB (described below in reference to Figure 4). The main control PCB utilizes the data to determine information critical to proper operation of the motor 10, such as the relative position of rotor stack 58 to stator stack 30 (shown in Figure 2) and the speed of rotor stack 58. Therefore, the alignment of interrupter vanes 66a to rotor poles 68 (shown in Figure 2), and the alignment of stator stack 30 to optical sensor 74 is very important for proper motor operation.

[0031] Proper alignment of stator stack 30 to optical sensor 74 is accomplished by molding bridge 70 from the same core side of the mold as are stator locating ribs 40. Bridge 70 includes the sensor mounting structure, such as aperture 80 and mounting boss 72b, which precisely orient optical sensor 74 within bridge 70. Stator locating ribs 40 are keyed to stator stack channels 42 (shown in Figure 2), such that stator stack 30 is fitted into housing 14 in a precise orientation. Therefore, the tooling that defines the sensor mounting features in bridge 70 also defines locating ribs 40. The fact that both bridge 70 and the stator locating ribs 40 are incorporated into the core side of the mold insures that these important structural components are integrally formed on the same part

(i.e. housing 14). This serves to ensure that alignment of the optical sensor 74 relative to the position of stator stack 30 is controlled with great accuracy and further reduces the chance of misalignment of stator stack 30 during assembly of motor 10. It will also be appreciated this significantly reduces assembly time because particular care does not need to be taken in trying to manually align these components.

[0032] Figure 4 is an exploded view of the distal end of motor 10 (shown in Figure 2), showing how the components at the distal end of motor 10 are assembled. A main control PCB 82 fits behind optical sensor 74 while preferably a pair of capacitors 86, for example, large film capacitors, are mounted on a capacitor PCB 94 and housed in the bulge 18 integrated into the side of the motor housing 14.

[0033] Main control PCB 82 is potted in epoxy resin inside a plastic potting boat 98, which fits onto plastic boss 81 and another plastic boss (not shown) that extend up from motor housing 14. Additionally, main control PCB 82 has two wing-shaped aluminum heat sinks 102 and 106 fitted on opposite peripheral edges of main control PCB 82. Four switching devices, in one preferred form comprising insulated gated bipolar transistors (IGBTs), are secured to one of heat sinks 102 and 106, and also soldered to main control PCB 82. Additionally, four diodes are fitted to the other one of heat sinks 102 and 106. After all of components 74, 78, 82, 94 and 98 are inserted into housing

14, vented end cap 22 is placed over the components and secured to housing 14.

[0034] There are multiple connections (not shown) to main control PCB 82, which include the incoming AC power, connections to the motor leads, connections to optical sensor 74, and finally signal level leads coming from the various switches on the product, such as a trigger switch, a table position latch switch, or speed control potentiometers. These connections may be either directly soldered to main control PCB 82 and secured with potting compound or connected using terminals. All the external leads, such as AC power and signal level switch inputs, are bundled into a single, multi-conductor cable (not shown), which exits motor housing 14 on the side opposite bulge 18.

[0035] Figure 5 is an exploded view of motor housing 14 (shown in Figure 4), showing how capacitors 86 are slideably inserted into motor housing bulge 18. In order to implement brushless motor 10 in applications where a typical universal motor is commonly utilized, the overall axial length of the motor must be similar to the axial length of typical universal motors.

[0036] In the preferred embodiment, motor housing 14 includes bulge 18, which houses capacitors 86, thereby minimizing the overall axial length of motor 10. Capacitors 86 are soldered onto capacitor PCB 94 and then strapped to capacitor PCB 94 using fasteners 110, such as nylon cable ties. Stiffeners 114 are attached to the two opposing longitudinal edges of capacitor

PCB 94, thereby adding structural rigidity to capacitor PCB 94. In one embodiment, stiffeners 114 are temporarily attached to capacitor PCB 94, for example, using clips or a snap fitting. In an alternate embodiment, stiffeners 114 are permanently attached to capacitor PCB 94, for example, using glue or a bracket riveted to both capacitor PCB 94 and stiffeners 114. Stiffeners 114 fit into corresponding channels 116 along the inside wall of motor housing bulge 18. In the preferred embodiment, stiffeners 114 are drafted, and thus have a tapered shape.

[0037] Stiffeners 114, are slideably inserted into corresponding channels 116, which are also drafted, however the shape of stiffeners 114 and corresponding channels 116 are not so limited. End slots (not shown) at the base of motor housing bulge 18 and in vented end cap 22 (shown in Figure 1) capture the ends of capacitor PCB 94. Capacitor PCB 94 is electrically connected to main control PCB 82 using flexible lead wires 118 inserted through an aperture 120 in the side wall of housing 14. Preferably lead wires 118 are a ribbon cable, but could be any other suitable electrical connecting means.

[0038] Figure 6 is an exploded view of stator stack 30 (shown in Figure 2). In the preferred embodiment stator stack 30 comprises a stack of laminations, known as a "unified stack", which are interlocked, welded, cleated, or bonded to one another. A plurality of first insulating strips 122 are formed into the shape of stator slots 124, inserted into stator slots 124 before windings or coils 126 are inserted into stator slots 124, and extend at either end of stator

stack 30. A plurality of second insulating strips 128 (shown in Figure 7), commonly known as "topsticks" or "coil stays", are wedged between windings 126 and the mouth of stator slots 124 after windings 126 are inserted into stator slots 124, and extend at either end of stator stack 30. First insulating strips 122 and second insulating strips 128 provide a layer of electrical insulation between current carrying components of motor 10 and metal parts of motor 10 that a user would normally come into contact with, referred to herein as "accessible metal". For example, if motor 10 is used in a hand held power saw, rotor shaft 50 is considered accessible metal because it connects through conducting a metal-to-metal interface with the saw gearbox, which connects through a conducting metal-to-metal interface to a saw blade.

[0039] Figure 7 is an exploded view of stator stack 30 (shown in Figure 6), rotor stack 58, and shaft 50 (shown in Figure 2) showing a double insulation feature implemented in accordance with a preferred embodiment of motor 10 of present invention. Electronically commutated brushless motor 10 (shown in Figure 2) includes two layers of electrical insulation between accessible metal and parts of motor 10 in which electrical current flows. One layer of insulation comprises insulation tube 54 between shaft 50 and rotor lamination stack 58. Insulation tube 54 is constructed of a non-conductive, electrically insulating material such as fiberglass. Insulation tube 54 is pressed onto shaft 50 and rotor lamination stack 58 is then pressed onto insulation tube 54.

[0040] Another layer of insulation comprises the plurality of first insulating strips 122 and the plurality of second insulating strips 128. First insulating strips 122 are constructed of an electrically insulating material and fit into stator slots 124 prior to stator windings 126, such that first insulating strips provide a first portion of an electrical barrier between stator windings 126 and stator laminations 30. Second insulating strips 128 are also constructed of an electrically insulating material and are fitted into stator slots 124 after windings 126, such that second insulating strips 128 provide a second portion of an electrical barrier between stator winding 126 and stator laminations 30. The combination of first insulating strips 122 and second insulating strips 128 totally encompass the part of stator winding 126 inserted into stator slots 124, thereby providing a complete electrical barrier between winding 126 and stator stack 30. The insulating material used to construct first insulating strips 122 and second insulating strips 128 can be any suitable insulating material, for example, Mylar®, or a laminated composite of Mylar® with other materials such as rag paper or Nomex®.

[0041] Thus, insulating tube 54 disposed between shaft 50 and rotor stack 58, and the combination of first insulating strips 122 and second insulating strips 128 disposed between stator stack 30 and windings 126, provide a double insulation barrier against possible electrical shock should a user come into contact with accessible metal if a malfunction has occurred in the motor that

would otherwise cause electrical current to be in contact with accessible metal portion of the tool.

[0042] In an alternate embodiment housing 14 is constructed of a non-conductive material, thereby providing a supplemental layer of insulation within motor 10, in addition to the double insulation barrier described above. In another alternate embodiment, stator stack 30 is installed into motor housing using a non-conductive intermediate device, such as a molded plastic cradle, housing, or sleeve (not shown) into which stator stack 30 is inserted prior to being installed in housing 14. In this embodiment the plastic cradle would house stator stack 30 and would then fit into housing 14 thereby providing an alternate supplemental layer of insulation between parts of motor 10 in which electrical current flows and accessible metal.

[0043] Figure 8 is cross-sectional view of motor 10 (shown in Figure 2). In the electronically commutated brushless motor 10, air is drawn in through vented end cap 22, passes around the periphery of potting boat 98 and main control PCB 82, through channels created by extruded fins of aluminum heat sinks 102 and 106, continues over stator windings 126, passes through and around stator stack 30, through cooling fan 62, and exhausts out bearing end cap 26.

[0044] Potting boat 98 and main PCB 82 impede this airflow by causing an obstruction to a more direct flow of air into heat sinks 102 and 106.

The obstruction to airflow is further compounded by the molding process of housing 14. To effectively mold and produce housing 14, it must have draft added on both its internal core and external cavity sides of the mold. The draft closes the space between an internal wall of housing 14 and potting boat 98, thereby further restricting the airflow around through the motor.

[0045] Figure 9 is a schematic of the housing 14 (shown in Figure 2), showing the location of the parting line of the core and cavity used to mold housing 14. Housing 14 is designed to provide more area at the distal end, or rear, of housing 14 than known electronically commutated brushless motor housings. The increased area provides greater space around potting boat 98 (shown in Figure 4), which allows improved airflow through the motor 10 (shown in Figure 1).

[0046] Generally, when designing molding tools for a motor housing, such as motor housing 14, a specified angle of draft θ in the core, and a specified angle of draft α in the cavity, are designed into the molding tools to make removal of the housing from the mold easier. The draft incorporated into the core and cavity create taper in the sidewall of the housing that extends away from a parting line between the core and cavity. Specifically, draft angle α in the cavity creates taper in an exterior surface of the housing.

[0047] The interfacing surface at which the core and cavity meet, and separate, during the molding process is referred to as the parting line. Draft

angles θ and α are measured from a plane perpendicular to the parting line. Since draft angle α creates taper in the exterior surface, the further the parting line is away from the distal end of the housing, or the closer the parting line is to the proximal end, the smaller the outside diameter of the distal end of the housing will be. The inside diameter of the distal end of the housing directly relates to the outside diameter. Thus, the further away the parting line is from the distal end of the housing, the smaller the inside diameter of the distal end will be, thereby providing less area for air to flow in the distal end of the housing.

[0048] Referring to Figure 9, the parting line of housing 14 is shown located closer to the distal end "D" of housing 14, rather than at, or near, the proximal end "P" of housing 14, as is generally the case in known motor housings. Having the parting line located closer to the distal end D of housing 14 reduces the amount of taper of exterior surface 130, and therefore provides an increased outside diameter of the distal end, which in turn provides an increased inside diameter of the distal end of housing 14. The increased inside diameter increases the area at the distal end, thereby providing more room for air to flow around potting boat 98 (shown in Figure 4).

[0049] Therefore, electronically commutated brushless motor 10 provides a modular motor that fits the existing mounting schemes for typical universal motors. Motor 10 includes a housing having a bulge wherein two large capacitors are placed, thereby providing a brushless motor having an overall axial length comparable to typical universal motors. Additionally, proper

alignment of the position sensor to the stator is achieved by molding the mounting features for both the position sensor and the stator using the same molding core. Furthermore, motor 10 implements a double insulation design in an electronically commutated brushless motor. Even further, the design of motor 10 provides improved airflow through the motor by moving the parting line of the molding core and cavity, thereby permitting the housing to be molded using less taper, which in turn allows more space for air to flow around the electronics control module of the motor.

[0050] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.